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# APPENDIX A

## Intelligent Transportation System Benefits

## FREEWAY MANAGEMENT SYSTEMS

Freeway management systems have demonstrated benefits over an extended period of time and in several measurable Measures of Effectiveness (MOEs), including travel time, travel speed, freeway capacity, collision experience, fuel consumption, and emissions.

Table 1 - Summary of Freeway Management System Benefits

Travel time	Decrease 20% - 48%
Travel speed	Increase 16% - 62%
Freeway Capacity	Increase 17% - 25%
Accident rate	Decrease 15% - 50%
Fuel consumption	Decrease fuel used in congestion 41%
	Decrease CO emissions 122,000 tons annually
Emissions (Detroit)	Decrease HC emissions 1400 tons annually
	Decrease NOx emissions 1200 tons annually

A longitudinal study of the freeway management system including ramp metering in the Seattle, Washington, area over a six-year period shows a growth in traffic of 10% to 100% along various segments of I-5 while speeds have remained steady or increased up to 48%, and accident rates have fallen consistently to a current level of 62% compared to the base period. The improvements have occurred while average metering delays at each ramp have remained at or below 3 minutes. The Minnesota DOT's Traffic Management Center, which operates freeways in the Minneapolis area, has produced the following experience: Capacity is 2200 vplph compared with 1800 prior to the use of the ramp meters. Average speeds have risen from 34 mph to 46 mph. Accident rates on I-35W before management were 421 per year and are now 308 per year. Annual accident experience on I-35W after management is 2.11 collisions/MVM compared to 3.40 before management was instituted. A survey of traffic management centers using ramp metering reported similar findings. In addition to speed increases of 16% - 62% and throughput increases of 17% - 25% that were frequently used to justify the installations in a benefit/cost sense, accidents in freeway systems under freeway management were reduced between 15% and 50%. While some other freeway improvements were implemented during the study periods, the combination of geometric, vehicle, and operational procedures showed significant reductions in accident rate. The initial freeway management system in Minneapolis was developed as a demonstration project in 1968. Expansions are justified by user benefits and are evaluated against other no-build options. As an approximate comparison, freeway expansion costs \$2 million per lane-mile while a complete implementation of an urban corridor costs \$500,000 per freeway mile plus the cost of a freeway management center. If the existing freeway is four lanes, installing a TMC could add about half the capacity of an additional lane at about 1/8 the cost.

As a result of reduction in delay and travel time, emissions will also be reduced. According to analysis in considering expansion of the Detroit freeway management center, delay under incident conditions would be reduced by about 40%, resulting annually in a reduction of 41.3 million gallons of fuel used (42%) and a reduction of carbon monoxide emissions by 122,000 tons, hydrocarbon emissions by 1400 tons, and oxides of nitrogen emissions by 1200 tons. These estimates assume that the freeway management system would not change vehicle miles traveled. This analysis established the benefits of expanding the system in 1988; however, the expansion could not proceed due to budgetary constraints and competing projects. The key element in allowing this expansion was the availability of Congestion Management/Air Quality funding authorized under ISTEA.

## TRAFFIC SIGNAL SYSTEMS

Transportation authorities have been installing progressively more flexible traffic signal systems since the first computerized systems were commissioned in the early 1960's. Benefits have been reported in areas including travel time, travel speed, vehicle stops, delay, fuel consumption, and emissions.

Among the earliest reported benefits, a 1966 project in Wichita Falls, Texas, reported a 16% reduction in stops, a 31% reduction in vehicle delay, an 8.5% reduction in accidents, and an increase in speeds of over 50%. This analysis compared the computerized system to the single-dial system it replaced.

Table 2 - Summary of Traffic Signal Systems Benefits

Travel time	Decrease 8% - 15%
Travel speed	Increase 14% - 22%
Vehicle stops	Decrease 0% - 35%
Delay	Decrease 17% - 37%
Fuel consumption	Decrease 6% - 12%
Emissions	Decrease CO emissions 5% - 13%
	Decrease HC emissions 4% - 10%

The Fuel Efficient Traffic Signal Management (FETSIM) and Automated Traffic Surveillance and Control (ATSAC) programs in California showed benefit/cost ratios of 58:1 and 9.8:1 respectively. ATSAC, which includes computerized signal control, reported 13% reduction in travel time, 35% reduction in vehicle stops, 14% increase in average speed, 20% decrease in intersection delay, 12.5% decrease in fuel consumption, 10% decrease in HC, and 10% decrease in CO.

A Texas state program called Traffic Light Synchronization (TLS) has installed 166 systems in phase I and an additional 73 in phase II. TLS analysis shows a benefit/cost ratio of 62:1. The TLS was funded through Oil Overcharge funds made available through the Texas Governor's Energy Office. The City

of Abilene installed a closed-loop signal system with hardware interconnect and modem link back to a shop computer. A portion of the funding for the Abilene upgrade came from a bond issue that specifically included the upgrade and the remainder came through the TLS program. The system upgrade was partly to move traffic better and partly to replace an antiquated system that was causing difficulty in locating replacement parts. The portion of funding on the bond issue competed with other projects in the public works budget for priority. The City of Abilene report indicates overall impacts as shown in Table 3.

Table 3 - Results from Abilene Signal System Upgrade

Travel time	-13.8%
Travel speed	- 22.2%
Number of stops	-0.3%
Delay	-37.1%
Fuel consumption	-5.5%
CO Emissions	-12.6%
HC Emissions	-9.8%
Nox Emissions	-4.2%

The FAST-TRAC program in the Detroit area, which includes the SCATS adaptive signal control system, has seen the virtual elimination of certain types of accidents as a result of the installation of a traffic management system and related improvement to intersection geometrics and signal phasing. Injury accidents have decreased 6%, injuries decreased 27%, serious injuries decreased 100% during the study period, and left turn accidents decreased 89% while peak hour, peak direction speeds increased 19% and intersection delay decreased by up to 30%. During the study period, minor and property damage only accidents increased (21% in total number of accidents) and delays on minor street intersection approaches increased. FAST-TRAC is being deployed using designated federal funds.

The city of Toronto evaluated the SCOOT signal control system on two corridors and the CBD network, totaling 75 signals. During an evaluation performed over a two-month period comparing the SCOOT implementation to a "best effort" fixed timing plan, the network showed decreases in travel time of 8%, in vehicle stops of 22%, in vehicle delay of 17%, in fuel consumption of 6%, in carbon monoxide emission of 5%, and in hydrocarbon emissions of 4%.

Simulation and analysis have predicted that traffic adaptive signal controls could further reduce delays and emissions compared to the currently implemented systems under certain conditions. In simulations performed for the National ITS Architecture Program using non-proprietary adaptive algorithms, delay reductions of well over 20% were observed when traffic patterns deviated from predicted

levels.

## INCIDENT MANAGEMENT PROGRAMS

Incident management programs also follow an evolutionary route to full deployment. Frequently, incident management programs become part of the mission in expanding freeway management centers. Many of the existing incident management systems such as the Highway Helper Program in Minneapolis, the Incident Management component of the CHART Program in Maryland, and the Emergency Traffic Patrol in Illinois began as "eyes and ears" of motorists, incorporating technology such as cellular call-in, loop detectors, video monitoring, and video detectors as technology and budget constraints allowed. Incident management programs show benefits in incident clearance times and are expected to reduce fatalities.

Table 4 - Summary of Incident Management Program Benefits

Incident clearance time	Decrease 8 minutes for stalls
	Decrease wrecker response time 5 - 7 minutes
Travel time	Decrease 10% - 42%
Fatalities	Decrease 10% in urban areas

Incident management programs show concrete promise of reducing the 50% - 60% of traffic congestion attributable to incidents. The Institute of Transportation Engineers has estimated 10% - 42% decreases in travel time for incident management programs included in freeway management systems. The Maryland CHART program is in the process of expanding to more automated monitoring with lane sensors and video cameras. CHART funding comes from a variety of sources including the state budget process and application for federal programs such as Congestion Management/Air Quality funding and Interstate Discretionary funding. This program is expected to have about a 10:1 benefit/cost ratio according to draft analyses. The Minnesota Highway Helper Program reduces the duration of a stall (the most frequent type of incident representing 84% of service calls) by 8 minutes. Using representative numbers, annual benefit through reduced delay totals \$1.4 million for a program that costs \$600,000 to operate. The reduction in secondary collisions attributable to the incident management program is difficult to estimate due to the coordinated freeway management program in the area.

Using video monitoring can also aid the clearance of an incident. The City of Richardson, Texas, tied the operator of the city's towing concession into the roadway monitoring network with an investment of roughly \$200. Using the information provided by the camera, the tow truck dispatcher can position appropriate equipment near the collision site prior to the request for service from the police department. This advance notice reduces the response time for incident clearance by 5 - 7 minutes on average and greatly improves the ability to send equipment that will handle the active incident.

In addition to delay reduction benefits, incident management programs are expected to benefit safety and emission reduction efforts. An analysis of the accident statistics on several California arterials and expressways shows that secondary accidents represent an increase in accident risks of over 600%, without controlling for climatic or other conditions. According to draft analysis based on data from the Fatal Accident Reporting System, reduction of incident notification times on urban freeways from the current average of 5.2 minutes to 3 minutes would result in a fatality reduction of 10% annually, or a national total of 212 lives if all freeways nationwide were under such a program. A reduction to two minutes would reduce fatalities by 308 annually. For comparison, the San Antonio TransGuide project has an incident detection goal of two minutes.

## MULTIMODAL TRAVELER INFORMATION SYSTEMS

Traffic and traveler information are popular with consumers and systems that provide such information are producing data that anticipate system benefit when wider deployment occurs. Traveler information programs using variable message signs and highway advisory radio are funded out of highway operations budgets. Programs using kiosks and in-vehicle devices are in the pilot project stage and are funded through operational testing programs. Telephone information is making the transition from pilot to operational status. Studies have produced benefits in reducing travel delay and travel time, and predict benefits in reducing emissions and fuel consumption.

INFORM (Information for Motorists) is an integrated corridor on Long Island, New York, including information via variable message signs (VMSs) and control using ramp meters on parallel expressways and some coordination on arterials. The program stretches back to concept studies in the early 1970s and a major feasibility study performed from 1975 to 1977. The implementation progressed in phases starting with VMSs, followed by ramp meters in 1986 and 1987, and completed implementation by early 1990.

Table 5 - Summary of Traveler Information System Benefits

Travel time	Decrease 17 minutes (20%) in incident conditions
	Decrease 8% - 20% for equipped vehicles
Delay	Decrease up to 1900 vehicle-hours per incident
Fuel consumption	Decrease 6% - 12%
Emissions	Decrease VOC 25% from affected vehicles
	Decrease HC emissions 33% from affected vehicles
	Decrease NOx emissions 1.5% from affected vehicles

Estimates of delay savings due to motorist information reach as high as 1900 vehicle-hours for a peak period incident and 300,000 vehicle-hours in incident related delay annually. Drivers will divert from 5% - 10% of the time when passive (no recommended action) messages are displayed and twice that when messages include diversion messages. Convenient alternate routes also impact diversion. Drivers will divert starting several ramps prior to the incident, with any one exit ramp carrying 3% - 4% of total approaching volume. This higher volume represents an increase in ramp usage of 40% - 70%. Accident frequency decreased slightly during the study, but data were insufficient to claim a significant trend.

Several traveler information projects are showing popularity and usage growth. The Los Angeles Smart Traveler project deployed 78 information kiosks in locations such as office lobbies and shopping plazas. The number of daily accesses ranged from 20 to 100 in a 20-hour day, with the lowest volume in offices and the greatest in busy pedestrian areas. The most frequent request (83% of users) was for a freeway map. Over half of the users requested MTA bus and train information. Users, primarily upper middle class in the test area, were overwhelmingly positive in response to a survey.

An automated transit information system implemented by the Rochester-Genesee Regional Transportation Authority resulted in an increase in calling volume of 80%, while a system installed by New Jersey Transit reduced caller wait time from an average of 85 seconds to 27 seconds and reduced caller hang-up rate from 10% to 3% while increasing the total number of callers. The Boston SmarTraveler has experienced 138% increase in usage from October 1994 to October 1995 to a total of 244,182 calls monthly, partly due to a partnership with a local cellular telephone service provider.

The Travlink test in the Minneapolis area distributed PC and videotext terminals to 315 users and made available transit route and schedule information, including schedule adherence information, as well as traffic incidents and construction information. For the month of July 1995, users logged on to the system a total of 1660 times, an average of slightly more than one access per participant per week. One third of the accesses to the system requested bus schedule adherence; another 31% examined bus schedules. Additionally, three downtown kiosks offering similar information averaged a total of 71 accesses per weekday between January and July of 1995; real-time traffic data were more frequently requested than bus schedule adherence.

Surveys performed in the Seattle, Washington, and the Boston, Massachusetts, areas indicate that 30% - 40% of travelers frequently adjust travel patterns based on travel information. Of those that change travel patterns, about 45% change route of travel and another 45% change time of travel; an additional 5% - 10% change travel mode.

Assuming that 30% of 96,000 daily callers change travel plans according to this breakdown, the impact of SmarTraveler in Boston on emissions has been estimated using the MOBILE5a model. On a daily basis, this adjustment of travel behavior nets an estimated reduction of 498 kg of volatile organic compounds, 25 kg of oxides of nitrogen, and 5032 kg of carbon monoxide representing reductions of 25%, 1.5%, and 33%, respectively, of these pollutants from travelers changing travel plans. While only 28,800 daily trips are expected to be affected in a metropolitan area with 2.9 million registered drivers, this represents significant reductions for participating travelers.

Simulations performed for the Architecture program using an urban scenario produced more encouraging indications of potential ATIS benefits . For networks with congestion causing increases of up to a factor of 3 from free flow travel time but before saturation, equipped vehicles experience a 8% - 20% advantage in travel time. As the network becomes saturated and before congestion significantly affects travel time, the advantage of equipped vehicles is smaller. For experienced commuters, the simulation predicts an aggregate travel time benefit of 7% - 12%. The relative benefit to longer trips is more significant than benefit to shorter trips, consistent with a greater opportunity for advantageous diversion. The simulations were performed using an ATIS market penetration level of 5%. A separate simulation study predicted that pretrip information on roadway conditions could result in a delay reduction of 15% when a capacity reducing incident occurs and off-road travel options are present.

Studies also indicate interest in traffic information on the part of the traveler as well as willingness to react to avoid congestion and delay. In focus groups for the Atlanta Advanced Traveler Information Kiosk Project, 92% - 98% of participants found the current information on accidents, alternate routes, road closures, and traffic congestion to be useful and desirable. A survey in Marin County, California, showed that if regular commuters had been presented with alternate routes including travel time estimates, 69% would have diverted and would have saved an average of 17 minutes. A pilot project in the Netherlands found a 40% increase in route diversions based on traffic information by the 300 vehicles equipped with FM sideband data receivers.

## TRANSIT MANAGEMENT SYSTEMS

For nearly a decade, transit properties and emergency vehicle operators have been installing and using vehicle location systems based on signpost, triangulation, LORAN, and GPS technologies. A recent study found 24 U. S. transit systems operating more than 10,000 vehicles under AVL supervision and another 31 in various stages of procurement. This represents a doubling of the number of deployed systems, with most new systems using a GPS-based location process. Five Canadian operators are using AVL on fleets totaling 3700 buses, including a 2300-vehicle fleet in Toronto. Coupled with computer-aided dispatching systems, vehicle location technologies are producing benefits in security, travel time, service reliability, and cost-effectiveness. Additionally, several operators have reported incidents where AVL information assisted in resolving disputes with employees and patrons.

Table 6 - Summary of Transit Management System Benefits

Travel time	Decrease 15% - 18%
Service reliability	Increase 12% - 23% in on-time performance
Security	Decrease incident response time to as little as one minute
Cost effectiveness	45% annual return on investment



Safety and security are major factors in decisions to install transit management systems. Situations benefiting from AVL and communication systems installed as part of transit management systems include medical emergencies as well as threats and crimes involving passengers and those observed by bus drivers. Some agencies report response times of as little as 1 to 2 minutes while others report reductions of about 40%. Agencies have reported improved cooperation with police after being able to precisely locate a bus involved in an incident and having a transit dispatcher assist in apprehending criminals using bus location information. Bus operators also report an increased sense of security with silent alarm and vehicle location capabilities.

AVL and dispatching systems have most directly improved schedule adherence. The Mass Transit Administration in Baltimore reported a 23% improvement in on-time performance by AVL-equipped buses. The Kansas City Area Transportation Authority improved on-time performance by 12% in the first year of operation using AVL, compared to a 7% improvement as the result of a coordinated effort between 1986 and 1989. Preliminary results from Milwaukee indicate a 28% decrease in the number of buses more than one minute behind schedule. Coordination between transit systems and traffic signal systems has also demonstrated operational benefits. Allowing buses to either extend green time or shorten red time by only a few seconds reduced bus travel time on a test route in Portland by 5% to 8%.

An AVL system provides a rich source of data for analyzing bus operations. Examining AVL data collected in Kansas City led to a schedule revision that reduced the 200-vehicle fleet by 7 buses while reducing scheduled travel times by up to 10%. The Kansas City Area Transportation Authority reported an annual operating expense reduction of \$0.5 million based on a \$1.1 million investment. Other transit systems have reported reductions in fleet size of 2% to 5% due to efficiencies of bus utilization. Alternatively, the efficiency gains could be used to increase frequency by the same amount. Using AVL data for analysis purposes also reduces the need for staff to perform schedule adherence and travel time surveys. Estimates of savings range from \$40,000 per survey to \$1.5 million annually.

## ELECTRONIC TOLL COLLECTION SYSTEMS (ETC)

Twelve authorities are currently using ETC, with two more scheduled to be operational by the end of 1995. The decision to deploy ETC is based on reduction in operating cost to the toll authority, coupled with the benefits of emission reduction and capacity increases.

Table 7 - Summary of Electronic Toll Collection System Benefits

Operating expenses	Decrease up to 90%
Capacity	Increase 250%
Fuel consumption	Decrease 6% - 12%
Emissions	Decrease CO emissions 72% per affected mile

Decrease HC emissions 83% per affected mile

Decrease NOx emissions 45% per affected mile

The Oklahoma Turnpike has been operating electronic toll collection for over four years with excellent results, including the ability to avoid staff layoffs for eliminated positions through attrition and reassignment. Statistics from the Turnpike include:

Annual cost to operate automated lane - \$15,800

Annual cost to operate attended lane - \$176,000

Electronic toll collection can greatly improve throughput on a per-lane basis compared with manual lanes. On the Tappan Zee Bridge toll plaza, a manual lane can accommodate 350 - 400 vehicles per hour while an electronic lane peaks at 1000 vehicles per hour. By replacing 8 manual collection stations with five electronic lanes using the multijurisdictional E-ZPass system, and implementing a movable barrier procedure to allow an extra peak direction lane, traffic speeds have increased from a crawling 8 - 12 mph to a flowing 25 mph. The New York State Thruway, which includes the Tappan Zee Bridge, benefits significantly from ETC in that expansion beyond 13 lanes for the toll plaza was not an option and the toll authority had implemented tandem operations on 5 of the lanes. Roughly 110,000 electronic toll tags are now in use on the Thruway.

The Oklahoma Turnpike Authority's Pike Pass program started operation on January 1, 1991. Through June 1994, 250,000 passes had been issued, of which over 90% (226,000) were still active, accounting for 35% of revenue. Using a protocol prepared for the Northeast States for Coordinated Air Use Management (NESCAUM), the Clean Air Action Corp. estimated toll booth emissions based on dynamometer tests and toll road observation at Muskogee Turnpike in Oklahoma, Asbury Plaza on the Garden State Parkway in New Jersey, and the Western Plaza on the Massachusetts turnpike. Percent change is, of course, dependent upon frequency of toll plazas. Per mile of impacted operation, the calculated average emissions are shown in Table 8.

## INTEGRATED SYSTEMS

The state of the art in transportation management is the integrated transportation management center. Centers operate freeways or traffic signal systems and incorporate staff and facilities for some or all of the following: fire and rescue, surface street signal control, freeway operations including ramp metering and toll collection, police, transit, and transportation research. Centers incorporating or moving toward collocation include the TransGuide Control Center in San Antonio, the State of Maryland CHART Operations Center, the Montgomery County Traffic Management Center, the Michigan Intelligent Transportation Systems Center in Detroit, and the Houston TranStar Center. The Atlanta Advanced Traffic Management Center is scheduled to be available for the 1996 Summer Olympics.

Few evaluations of integrated facilities are currently available; however, stories from integrated centers and the trend in developing them tell a compelling story about the value of such facilities. The San

Antonio TransGuide facility opened in the summer of 1995. The value of an integrated facility was demonstrated the week before the center opened when an industrial plant fire erupted within view of freeway video monitoring. Based on the visibility afforded at TransGuide, the fire was accessed and fought more effectively, possibly saving the lives of several firefighters. Both local police and fire were convinced of the wisdom of their investment in collocation.

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